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Reduction of Transmission Error Propagation in Adaptively Predicted, DPCM Encoded Pictures

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A new technique for reducing transmission error propagation in adaptively predicted, DPCM-encoded pictures is described. The basis for the technique is a generalization of the notion of predictor output attenuation, described by Graham, to include attenuation of the adaptive prediction function. Simulation results are presented that show that application of the technique to Graham's codec results in significant reduction in error propagation without degradation of picture quality. The technique requires no increase in transmission rate.

I. INTRODUCTION

This paper presents a new and simple technique to reduce error propagation in DPCM image coders that employ adaptive switching-type prediction. An analytical performance description of this technique has not been obtained. However, simulation results using the Graham[1] adaptation algorithm are presented that demonstrate that—in this case, at least—the technique can provide substantial reduction in channel error propagation without decreasing the transmission rate.

The class of coders considered is those which adaptively choose one of Q fixed predictors F_q, $q = 1, 2, \cdots, Q$, according to a decision rule that operates on the previously reconstructed pixels in the local past vicinity of the element to be predicted. If x_{ij} is the ith pixel on the jth line of the input raster, and y_{ij} is the vector of reconstructed pixels in the local past vicinity of (i, j), then the adaptive predictor has the form

$$\hat{x}_{ij} = F(y_{ij}), \tag{1}$$

where $F(\cdot)$ is one of Q fixed functions $F_q(\cdot)$, $q = 1, \cdots, Q$, with q chosen according to a decision rule operating on y_{ij},

$$q = D(y_{ij}). \tag{2}$$

The encoder and decoder use the same decision rule to determine q, but the decoder must base its decision upon its possibly contaminated version of the reconstructed past scene.

An example of (1) and (2) is given by Graham's predictive encoder. Here $Q = 2$ with

$$\begin{aligned} F_1(y_{ij}) &= y(i-1, j) \\ F_2(y_{ij}) &= y(i, j-1) \end{aligned} \tag{3}$$

and

$$D_{ij} = \begin{cases} 1; & \text{if } |y(i-1, j-1) - y(i, j-1)| \\ & \quad < |y(i-1, j-1) - y(i-1, j)| \\ 2; & \text{otherwise.} \end{cases} \tag{4}$$

It is well known that, for a fixed transmission rate, adaptive prediction generally results in a more accurate coded version of the image, particularly on edges within the picture where large changes in amplitude occur along one dimension. However, a serious problem generally arising from such adaptation is the response of the system to channel errors. Generally, the effect of an error propagates over a larger area of the picture when an adaptive predictor is used than when a fixed predictor is used. This occurs because transmission errors not only (*i*) contaminate the value of the elements used by the receiver in the function $F(\cdot)$ when the receiver's choice of q is correct, but can also (*ii*) cause an error in the receiver's choice of q. Note that effect (*i*) is present in nonadaptive coders and is defined as occurring in adaptive coders when the correct choice of q is made by the decoder. Effect (*ii*) is unique to adaptive prediction and is potentially more grievous since the transmitter and receiver then use different choices for the prediction function $F(\cdot)$—a result that, once started, can propagate. An example of the effect of transmission errors in adaptive DPCM is shown in Fig. 1. In this example, Graham's three-bit codec is used over a binary symmetric channel having bit error probability of 10^{-4}. Figure 2 shows the difference between the output of this system with and without transmission errors.

II. PREDICTOR OUTPUT LEAK

As observed by Graham and others, the effect of transmission errors can be reduced by attenuating the predictor output by a constant α, $0 \le \alpha \le 1$. In general, a bias term can be introduced so that $\hat{x}_{i,j}$ assumes the form:

$$\hat{x}_{ij} = \alpha F(y_{ij}) + (1 - \alpha)\eta, \tag{5}$$

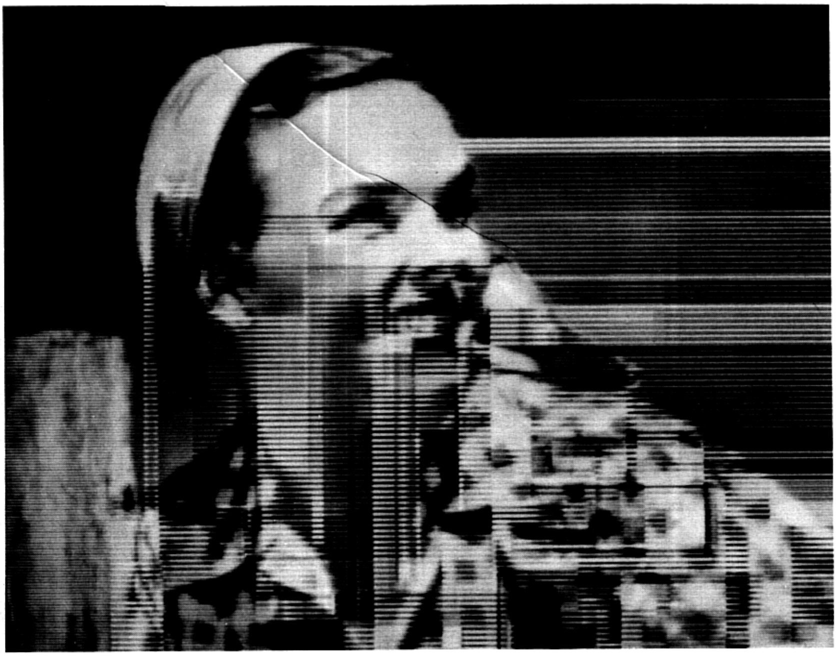

Fig. 1—Effect of 10^{-4} channel bit error probability on output picture: Graham 3 bit/pel codec.

where η is a constant in the span of possible picture values. A possible choice of η is the mean of x_{ij},

$$\eta = E\{x_{ij}\}. \tag{6}$$

Other choices, however, can give subjectively better results depending upon context and system nonlinearities.

Equation (5) can be viewed as a weighted combination of *locally inferred* and *globally given* knowledge about x_{ij}. A value of $\alpha < 1$ has the effect of decreasing the memory of the closed reconstruction loop, and the bias term causes the output to tend toward η. The quantity quantized and transmitted has the form

$$x_{ij} - \hat{x}_{ij} = \alpha[x_{ij} - F(y_{ij})] + (1 - \alpha)[x_{ij} - \eta], \tag{7}$$

which is seen to consist of both DPCM and PCM information. As α varies from one to zero, the system changes from DPCM to PCM. Therefore, attenuation of predictor output as in (5) trades error-propagation attenuation with transmission rate. It should be observed that the technique described by (5) will also reduce error propagation in non-adaptive codecs. Also, the technique does not directly address the problem of the *choice* of q and is therefore a remedy more closely connected to type (*i*) errors than to type (*ii*).

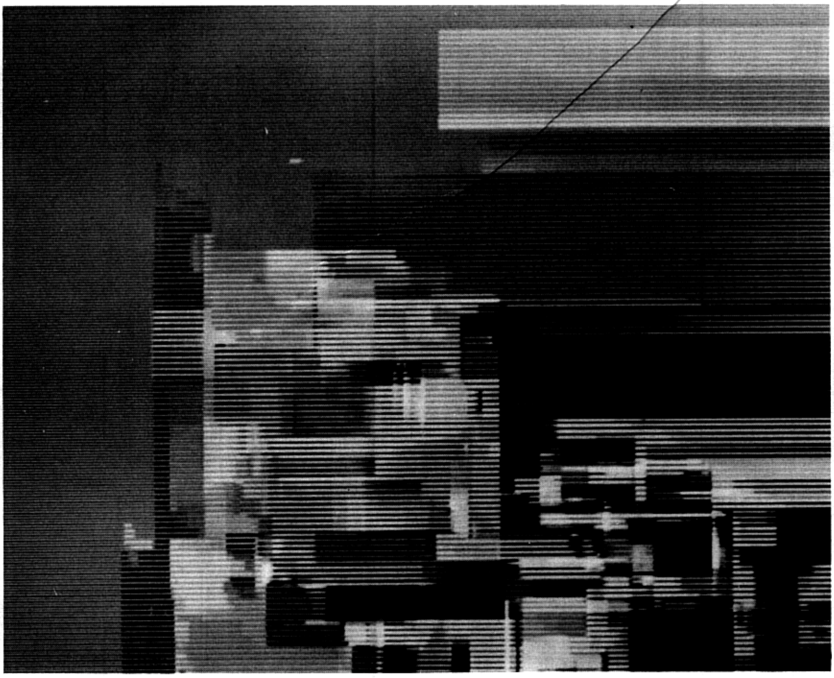

Fig. 2—Difference between output of Graham codec with and without transmission errors.

Using the Graham system, it was found that α could be reduced to $15/16$ before degradation in the output caused by quantization noise becomes visible. The reduction in error propagation resulting from (5) (with η set to 128) is shown in Fig. 3. The difference of the coded picture with and without channel errors is shown in Fig. 4. Although an improvement is obtained with this approach, the next section shows that substantially greater improvement is possible.

III. PREDICTION FUNCTION LEAK

Since the second effect of channel errors in an adaptive codec is to make the value of q uncertain, the receiver loop must in fact estimate the *function* $F(\cdot)$ as well as x_{ij}. In analogy with (5) we introduce a constant β, $0 \leq \beta \leq 1$, and set (at both transmitter and receiver)

$$\hat{F}(\cdot) = \beta F(\cdot) + (1 - \beta)\bar{F}(\cdot), \tag{8}$$

where $\bar{F}(\cdot)$ is a fixed predictor. A reasonable choice for $\bar{F}(\cdot)$ is the mean of F_q,

$$\bar{F}(\cdot) = \sum_{q=1}^{Q} F_q(\cdot)P(q), \tag{9}$$

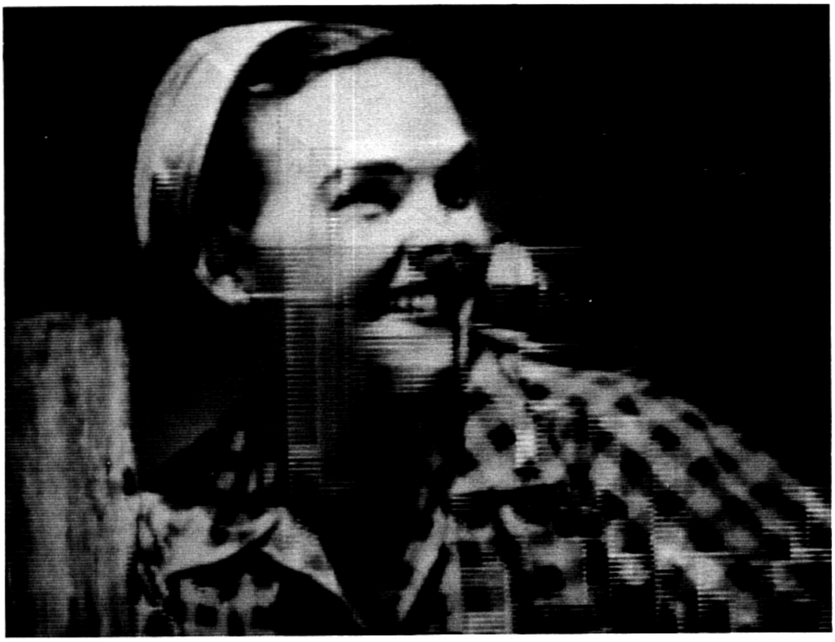

Fig. 3—Reduction of transmission error propagation using predictor output leak ($\alpha = {}^{15}/_{16}$, $\eta = 128$, 10^{-4} bit error probability).

where $P(q)$ is the *a priori* probability of q. Other choices for $\bar{F}(\cdot)$ are possible.

Note that, as β varies from one to zero, a system using $\hat{F}(\cdot)$ will change from fully adaptive DPCM to nonadaptive DPCM. The smaller the value of β, the closer the predictor to being fixed, and the smaller the effect of error propagation due to using the wrong predictor. Note also that (9) is an approach that is applicable only to adaptive codecs. Because of this, we view this technique as a remedy for the second error class (*ii*) described in Section I.

The concept of prediction function leak has been applied to the Graham predictor and has successfully reduced error propagation. The predictor used in this experiment is:

$$\hat{x}_{ij} = \hat{F}(y_{ij}), \tag{10}$$

where $\hat{F}(\cdot)$ is given by (8) using (3) to (4) and

$$\bar{F}(y_{ij}) = {}^{1}\!/_{2}(y(i-1, j) + y(i, j-1)). \tag{11}$$

It was found experimentally that β could be reduced to be between ¾ and ½ (depending upon the picture) before the ability of the adaptive predictor to respond to edges within the picture was compromised.

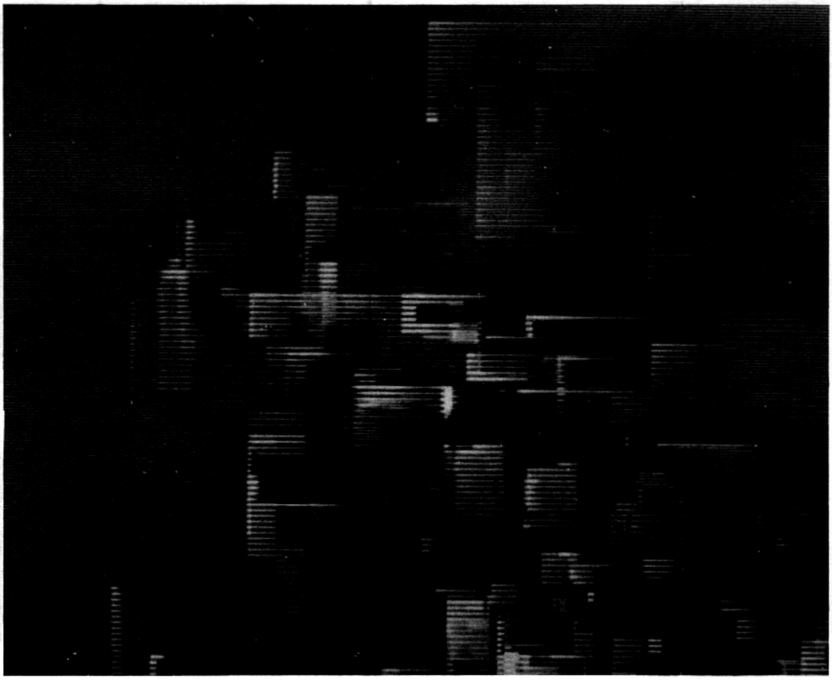

Fig. 4—Difference between output of codec with and without transmission errors ($\alpha = {}^{15}\!/\!_{16}$, $\eta = 128$).

Fig. 5—Reduction of transmission error propagation using predictor output and prediction function leak ($\alpha = {}^{15}\!/\!_{16}$, $\beta = {}^{3}\!/\!_{4}$, $\eta = 128$, 10^{-4} bit error probability).

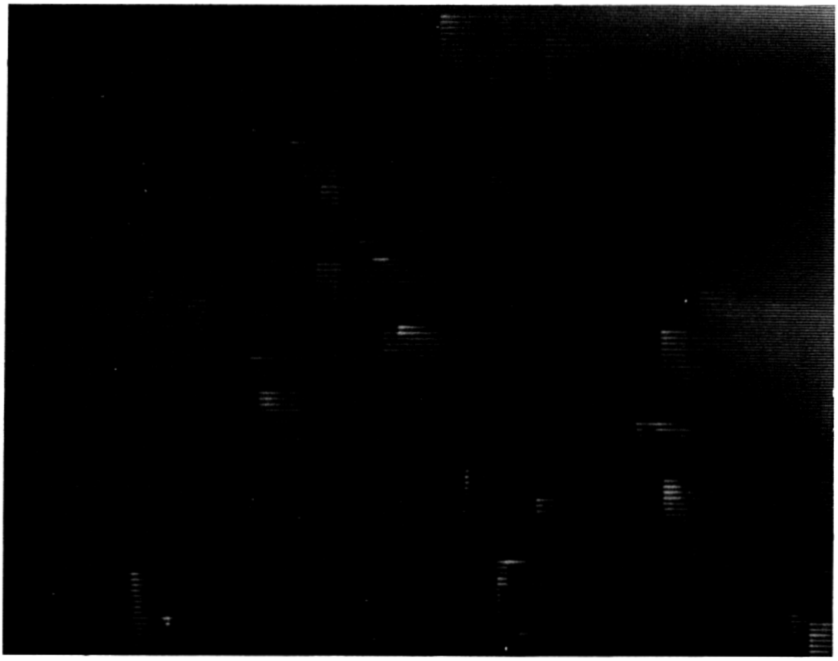

Fig. 6—Difference between output of codec with and without transmission errors ($\alpha = {}^{15}\!/_{16}$, $\beta = {}^{3}\!/_{4}$, $\eta = 128$).

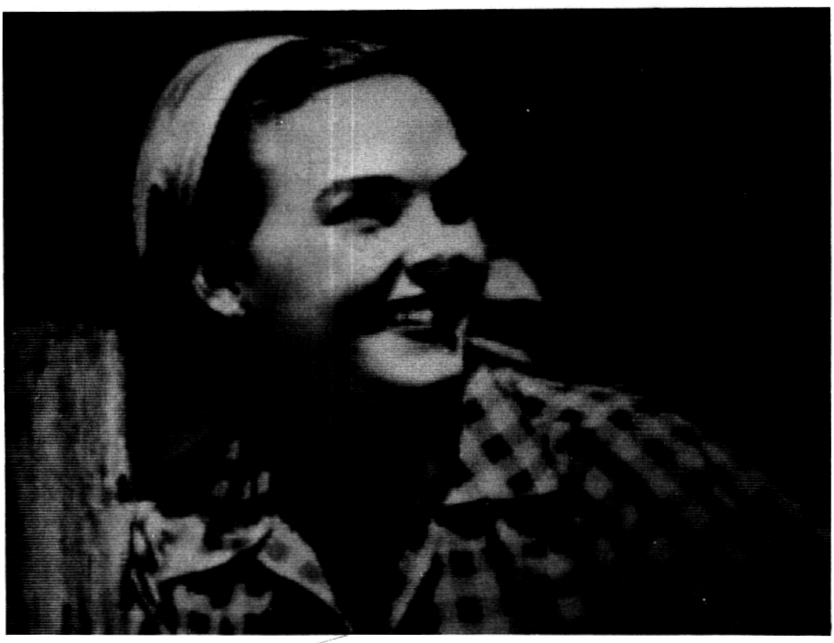

Fig. 7—Reduction of transmission error propagation using predictor output and prediction function leak ($\alpha = {}^{15}\!/_{16}$, $\beta = {}^{1}\!/_{2}$, $\eta = 128$, 10^{-4} bit error probability).

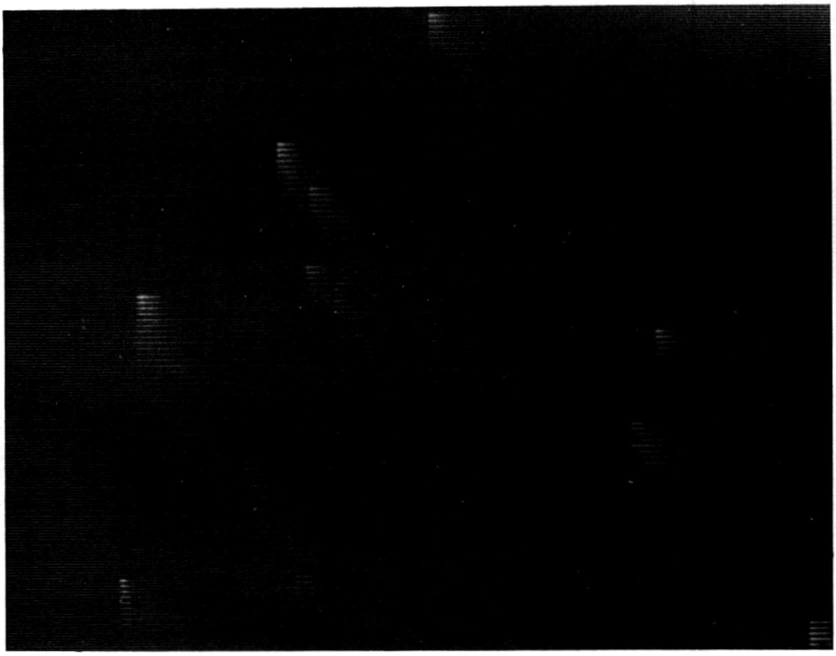

Fig. 8—Difference between output of codec with and without transmission errors ($\alpha = 15/16$, $\beta = 1/2$, $\eta = 128$).

Fig. 9—Quantizing noise of Graham codec.

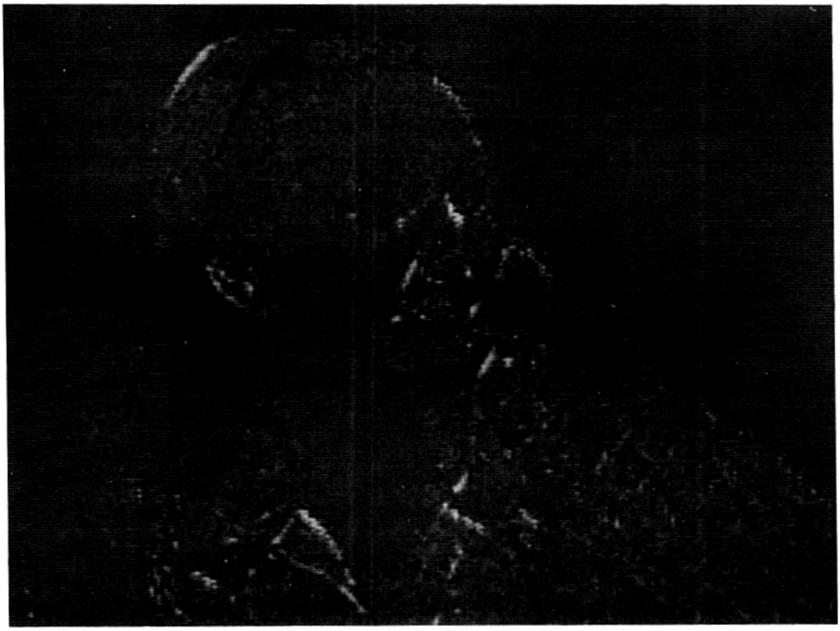

Fig. 10—Quantizing noise for $\alpha = {}^{15}\!/_{16}$, $\beta = 1$.

Fig. 11—Quantizing noise for $\alpha = {}^{15}\!/_{16}$, $\beta = {}^{3}\!/_{4}$.

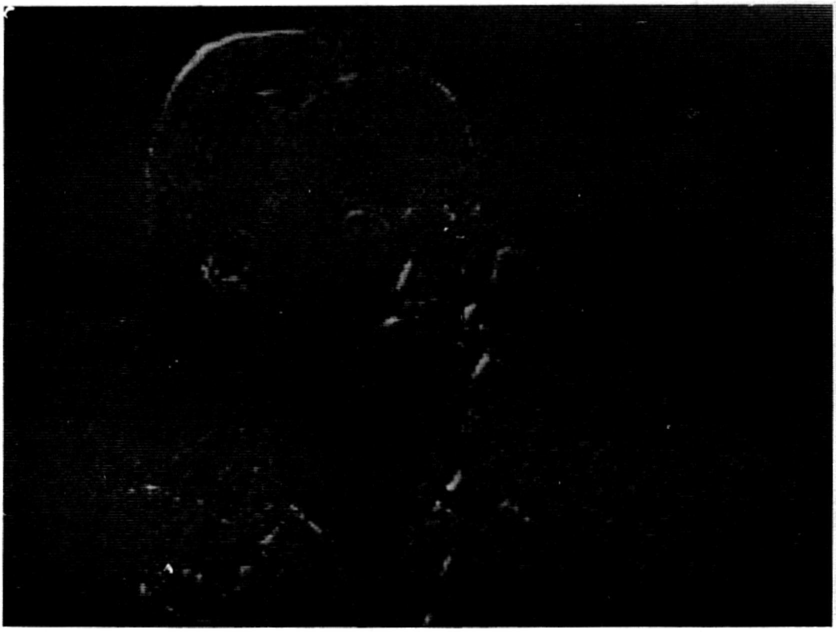

Fig. 12—Quantizing noise for $\alpha = 15/16$, $\beta = 1/2$.

When prediction function leak is used, it is possible to use predictor output leak to further reduce the effects of errors. The estimator is formed as:

$$\hat{x}_{ij} = \alpha\hat{F}(y_{ij}) + (1-\alpha)\eta$$
$$= \alpha\beta F(y_{ij}) + \alpha(1-\beta)\bar{F}(y_{ij}) + (1-\alpha)\eta. \qquad (12)$$

Pictures with the same transmission error patterns as those that occurred in the pictures produced using the original Graham predictor were processed using (12). In Fig. 5, $\alpha = 15/16$, $\beta = 3/4$ and $\eta = 128$. Figure 6 is the difference between pictures processed with this predictor with and without transmission errors. In Fig. 7, $\alpha = 15/16$, $\beta = 1/2$, and $\eta = 128$. Figure 8 is the error difference picture of this coder. As seen from these pictures, leaking the prediction function significantly reduces the effect of transmission errors. Analysis of this effect has been hindered by the nonlinear nature of the equations and the fact that the quantities involved exist on a two-dimensional field.

Figures 9 through 12 show the encoding (quantizing) noise for each of the systems previously described in this paper. By comparing Fig. 9 with 11 and 12, it can be seen that, for β equaling $3/4$ and $1/2$, prediction function leak *reduces* encoding noise along edges within the picture. In fact, pictures transmitted with these values of β over an error-free channel are preferable to those transmitted with the original Graham codec since edge serration, which sometimes occurs when a switching-type predictor is used, is reduced. Figure 10 shows that the introduction of predictor output leak alone does not produce the same beneficial effect.

REFERENCE

1. R. E. Graham, "Predictive Quantizing of Television Signals," IRE Wescon Convention Record, Part 4, 1958, pp. 142 to 157.